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Date: December 16, 1998

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Provisional Patent Application

Title: Elastomeric Interconnection Concepts
Inventors: Roger Weiss

Background of the Invention

As electronic systems get smaller, faster and lower cost, the classic methods of separable interconnection need to be replaced with new technologies. One such technology is based on anisotropic conducting polymer materials. Anisotropic Conducting Elastomers (ACE) are elastomers which conduct in one direction but are insulators in the other direction. One such example is ECPI - (Elastomeric Conducting Polymer Interconnect) a material developed by Lucent Technologies - Bell Laboratories. This material is formed by magnetically aligning fine magnetic particles in sheets of uncured silicone such that the particles form arrays of electrically isolated columns. These columns are frozen in place as the silicone cures. When a layer of ECPI is compressed between two electrical conductors the particles in the compressed column come into contact with each other and the conductors, forming an electrically conductive path. Conductivity of the column remains over a compression range which is a function of the material design. This range, often referred to as the material's dynamic range, provides compensation for the lack of coplanarity of the conductors. This is often referred to as "coplanarity compensation".

In a typical application of ECPI the interconnect formed replaces the soldered interconnect to allow a separable interconnection. This can be required for testing the device, aging the device (burn-in) and for final application in the OEM product. One such example is in a Land Grid Array (LGA) where an array of pads on a device needs to be

connected to a matching array on a board. A second example is when a Ball Grid Array (BGA), consisting of a device with an array of solder balls, is to be separably connected to a matching array on the board. In both of these examples, a layer of ECPI material placed between the device and the board can, when properly used, provide a reliable connection.

Although ACE materials have been demonstrated to work in these applications, there are several unique improvements that can enhance their ability to perform reliably. These improvements are to the polymer materials, the surface geometry of the material and to the connectors housing the material. These improvements are within the subject matter of this patent application.

The ECPI material developed by Lucent Technologies' Bell Labs was designed primarily for interconnecting pad to pad type interconnections such as the Land Grid Array. Although the materials function well in this area, they have limitations which can be improved by the introduction of novel concepts. These limitations are as follow.

- The outer particle layers can be removed during cleaning or handling. This will result in a loss of continuity. This is particularly true in the case of Plasma etched material where the surface of the material has been etched to better expose the particles so that more intimate contact with the pads can be made. The delicate nature of the surface can limit the use of the elastomer both in applications and number of recycles.

- When using the material as an interconnection medium between BGA devices, the spherical shape of the solder balls can bow the columns of particles outward from the contact center rather than compressing in straight paths. This can result in poor interconnection and shorting between adjacent pads.

- Elastomeric materials tend to behave like incompressible fluids. This means that as the

material is compressed, there must be space provided close to the point of contact for the material to flow in order for the column of particles to make contact with each other, the device and the board.

- Conventional pin-in-socket contacts provide for a metal to metal wiping action as the pin mates with the socket. This wiping action breaks through surface contaminants and corrosion products, such as oxides and sulfides. This is critically important to providing a low resistance connection. Elastomerics provide little or no wipe. Penetration of unwanted contaminants must be facilitated by the nodular structure of the particle at the surface of the elastomer. This can result in a variability in the material's performance.

- The material surface of the pad must be properly matched to the material that it contacts on the particle. A solder pad against a gold plated particle can result in the gold dissolving in the solder and forming a brittle alloy which will break and form a type of insulating layer referred to as *fretting corrosion*. The existing ECPI materials are plated with gold or silver which are not well matched to solder.

The above described limitations to the capability of conventional elastomeric conducting material can to varying extent be applied to both anisotropically conducting elastomeric materials that have magnetically aligned particles, and isotropically conducting materials such as those that are heavily filled with conducting metal. It can also be applied to some extent to anisotropic elastomeric materials that utilize other means than the magnetic alignment of particles to provide electrical and/or thermal connection.

Summary of the Invention, and Detailed Description of the Preferred Embodiments

Several concepts and improvements are described which can be used individually or in various combinations to address the above described limitations. These are described below with figures provided as needed.

Integrated Surface Pads

Figure 1a is a conceptual cross section of the typical elastomeric conductor using magnetically aligned particles. This drawing indicates the thin layer of polymer material that remains on the surface after manufacturing. This layer is penetrated by the particles as the material is squeezed between pad layers. Figure 1b shows the surface material etched away in a manner taught by patent 4,820,376 "Fabrication of CPI Layers" Lambert et al. The particles are now quite fragile and the material must be handled carefully to prevent the particles from dislodging. Figure 1c presents an embodiment of the present invention. The elastomeric material has an array of conducting pads (and other structures) formed on the surface in intimate contact with the surface, and in a preferred embodiment in contact with the surface particles as shown in Figure 1c. This pad array can be formed by sputtering, vapor deposition, plating or a combination of these methods that are well understood by those skilled in the metal surface formation industries.

The resulting pad(s) form a bond between the silicone and the surface particles which protects the surface particles and keeps them from dislodging. Furthermore, the pad forms an extended electrical contact area for reliably providing electrical contact. This

geometry is particularly well suited for interconnection to BGA devices. Each solder ball on the BGA will now contact a matching pad on the silicone which is tied to the surface particle of several particle columns as indicated in Figure 1c. The resulting structure will now compress straight, eliminating the bowing of the columns induced by a spherical solder ball.

Although the figure indicates pads formed on both surfaces of the elastomer, it is envisioned that pads and conductors can be formed on one or both surfaces and to be able to create a multiplicity of electrical paths as indicated in Figure 1c to augment the routing provided by the device and board.

The pad structure provides a readily cleaned protective layer, greatly increasing the usable life of the material. Furthermore, a secondary cleaning operation of the plasma etched material with integral pads will remove the surface particles from unwanted areas while leaving the particles only in the pad area. This will minimize the opportunity for unwanted electrical contact.

The pad thickness of the pad layer provides a space between adjacent pads for the incompressible polymer to flow (bulge) as the material is compressed. This allows the elastomeric material to be used in applications where no local expansion space is provided, such as with designs using solder mask around the lands causing the lands to be depressed relative to the surface of the solder mask.

The pad surface can be structured so as to optimize the interconnection to the opposing member. Its surface finish can be solder, gold or any material that is an optimum match of the opposing member. Different finishes can be provided on opposing sides of the elastomer pads to facilitate the interconnection of normally inappropriate materials such as

solder to gold.

As stated above, sharp aspirates are needed to puncture oxide layers and to provide a quality interconnection. These can be provided on the pad surface in a number of ways.

- If the pad is thin relative to the surface particle, the particle's form will protrude through the plating as indicated in figure 1f.

- By utilizing a secondary plating operation to form dendrites as taught in IBM patent 5,185,073 "Method of Fabricating Dendritic Materials" Bindra et al, or diamond shards as taught in patent 5,835,359 DiFrancesco, aspirates can be formed as needed. Figure 1g schematically indicates the appearance of these aspirates

- Chemical or mechanical methods such as etching and sand blasting will roughen the base metal of the pad surface while having little effect on the surrounding elastomer. A subsequent thin plating of a hard metal such as nickel followed by a thin surface plate will provide an ideal surface which is well populated with aspirates as indicated in Figure 1h.

A very robust and easily cleaned surface is needed for the maximum cycle life needed in the device test arena. The pad layer on the elastomer provides a durable conductor surface. The elastomer surface in between the pads can be coated with a debris resistant film such as a flexible solder mask which will be easily cleaned.

In another embodiment, the elastomeric material is constructed in a manner indicated in figure 1j. In the normal construction of elastomeric conductive sheet, a carrier film such as a 0.005" thick layer of Mylar is used to carry the elastomeric film through the manufacturing process. This carrier sheet is normally removed from the elastomer at the end of the assembly. In this embodiment, the normally used carrier sheet is modified by the addition of a thin support film as indicated in figure 1j. This film would have holes

formed in it on the pattern of the contacts. In one design it could be a 0.002" thick film of Kapton with 0.025" holes formed on 0.050" centers. Other features such as registration and mounting holes could also be formed in the Kapton sheet.

When the elastomer is formed it will fill the holes in the support film. When the carrier sheet is removed from the support film as indicated in Figure 1k, a structure consisting of elastomeric conductor and support film as indicated in Figure 1e remains. ℓ The support film seals the surface of the elastomer and provides additional dimensional stability to the structure. The exposed pads can now be etched and plated as described earlier, with aspirates as needed. The resulting structure as shown in figure 1m provides a stable, sealed surface which can be readily cleaned. This will facilitate repeated use such as that done with test sockets and burn-in sockets. 1

In another preferred embodiment, the structure shown in figure 1j - 1m can have 2 support films as shown in figure 1n, or a modified carrier sheet as shown in figure 1p. When these films are removed a small gap is left between the surface of the ACP pad and the surrounding area, as shown in figure 1q. This serves two purposes: it allows the ECPI to access lands which are surrounded by solder mask and are depressed relative to the solder mask (figure 1r) and it also provides a place for the elastomer to flow to during compression. The protruding pads may or may not be metalized as described earlier based on the application.

Registration of the array of pads to the lands can be achieved by the addition of other features to the Kapton sheet. In one preferred embodiment, 4 precision registration holes are placed in the Kapton sheet outside the array of pads. These holes match 4 equivalent holes in the printed wiring board. Alignment of the pads on the elastomer to the

lands on the board is facilitated with precision pins pressed through the holes in the Kapton into the matching holes in the printed wiring board. These precision pins can be molded onto the device alignment frame providing alignment of the ACE + device to the board in 1 piece part. The ACE material covering the registration holes in the Kapton should be easily penetrated by the pins. Other features, such as registration slots, can be added to the Kapton sheet to align it with the connector housing, support frames or other alignment and support devices commonly used.

Although the example indicates pads on one surface only, the concept can be extended to provide pads on both surfaces, with the support film on one or both sides of the elastomer. The concepts described above can be combined in several ways to address the interconnection needs of a specific application. Having read this disclosure, these combinations are obvious to one of ordinary skill in the art.

2. Separable Surface Pads

There are several applications where it is advantageous to having the pad layer as a separate structure or appliqué which would be mounted on top of the ACE. The appliqué would be aligned relative to the device and board, but the ACE would not require orientation relative to the pad layer. Figure 2a shows such a structure. With this structure the pad would serve as the interface between the ACE and the device contact. The ACE would provide the needed compliance to allow for interconnection between the components.

One preferred embodiment of the appliqué would consist of a non conductive sheet such as Kapton which has holes formed on the same grid as the contact array. These would be populated by small floating contact pads such as those depicted in figure 2b. These contacts would have a diameter comparable to the land or solder ball diameter, and a

height of about 0.010 to 0.020". They would have a reduced diameter section "waist" in the middle which would allow them to be captured in the hole in the Kapton. The compliance of the Kapton would allow for the pads to be snapped into the hole but would retain the pad under normal conditions. The pad could move up and down the length of the waist while being held in place laterally. These contact pads could be machined from metal such as brass using a screw machine tool, and barrel plated with gold or solder. They also could be molded from plastic and plated to create the conductive path. The plating process would start with an electroless copper plate and be followed with nickel and solder or gold as needed. These plating techniques are well known to those skilled in the art of plating. The mold insert could have a roughened surface in the area which generated the pad contacting surface. This would result in aspirates to penetrate the surface films.

In another embodiment, shown in figure 2c, the contacts described above are also molded out of plastic. In this embodiment the contact would also be formed with molded aspirates in the contact areas. Also the shape could be optimized to match the opposing contact. An integral molded lead frame would mechanically orient the plurality of contacts such that they were held on the contact grid, thus eliminating the need for the Kapton carrier. The contacts would be preferentially plated with the appropriate metal system to address the needs of the interconnection. The lead frame would, in its final state, not be plated, leaving it non-conductive. This can be facilitated by several different techniques.

One such technique is to use a double molding process, where the lead frame and contacts are molded from different plastics. The contacts would be from a plateable plastic and the lead frame from a non- plateable plastic.

In another method, the entire surface of the contact and lead frame would be plated with a thin flash of copper, providing a conductive path for electroplating. A non-plateable photo resist would be coated over the entire part, and processed to be removed from the contacts but remain on the lead frame. The assembly would then be electro-plated with nickel, followed by gold or solder etc. as needed. The photo resist on the lead frame would be removed, and the copper flash etched from the frame, eliminating conductive paths. The etch would not attack the solder or gold finish on the contacts.

In another method the contact pads could be preferentially metalized by masking the lead frame and applying metal by sputtering or other form of vapor deposition.

In a preferred embodiment, a Kapton carrier with holes on the component grid would be inserted into a molding press where plateable conducting contacts would be molded in each of the holes. These would have the needed geometry and aspirates formed in the mold. The resulting contacts would be electrolessly plated with materials that would not plate on the Kapton, providing the needed array of contacts.

The above described concepts can be combined in numerous ways to achieve the desired geometry. One such combination would be to mold a contact pad array with lead frame attached. This entire assembly would plated with the techniques described. The array of contacts would be gang inserted into a Kapton sheet with matching holes. As the array is inserted, the lead frame is removed and discarded.

Bulk Properties of Elastomer

The behavior of the elastomeric material is critical to the success of the ACE performance. Existing materials have poor elastic properties, and when formed into

discrete button-like contacts, tend to move like putty, taking a severe set. These materials exhibit little residual spring force. This impacts on the reliability of the contact, and virtually precludes multiple device insertions with different devices. Because these existing materials have poor elastic properties, an external spring member is required to create a contact force. Unfortunately, the elastomer flows continuously under the force. The conventional solution is to limit the flow with a stop. The net effect is a very low contact force.

A second problem with elastomers in sheet form is that they tend to behave like incompressible fluids. This requires that the connector system design provide for a place for the material to move.

Unique solutions are proposed which address these limitations.

1) "Perfectly" Elastic Elastomers

Magnetically aligned systems such as provided by ACE use very little metal, and the material tends to take on the elastic behavior of the base elastomer. New base elastomers have been developed which exhibit nearly perfect elasticity over a broad temperature range. Specifically, NuSil CF1-6755 (available from NuSil Technology, Carpinteria, CA) has been identified as having close to ideal behavior. In a preferred embodiment, an ACE material would be formed from a blend of from 5% to 25% magnetically aligned particles in a base of NuSil CF1-6755 or its equivalent (by equivalent is meant an elastomeric material that retains at least 90% of its modulus of compression over a temperature range of -50° C to 200°C). This combination will not take a set over a wide temperature range. What is claimed is the use of NuSil CF1-6755 silicone Blends or their equivalent in combination with a 5%-25% combination of magnetically aligned particles in ACE

materials for use in thermal and electrical connection.

When materials as described above are used to interconnect components to boards, external springs such as those required by the Thomas and Betts MPI socket, and the Cinch Synapse socket, are no longer required. Closure of the socket to a fixed displacement of the ACE material will establish a spring force which will remain fixed over the life of the product. What is claimed is a fixed displacement connector/socket design in conjunction with the elastomeric materials described above.

2) Incompressible Fluid Behavior

As stated earlier, these elastomers tend to behave like incompressible fluids. A distribution of space must be provided for the elastomer to flow into as the material is compressed. There are several unique ways that this can be done.

a) The surface structure can be modified by the addition of conducting pads as described above. A volume of space is created by the thickness of the pads. These pads would be on the same grid as the contacts of the device and board.

b) Introduce micro spheres of compressible material into the matrix of silicone. Small air filled particles would serve well in this application.

c) Utilize foamed elastomer materials which combine the elastic properties of the Nusil Silicone described above with the ability to create highly controlled size and distribution gas particles throughout the elastomer matrix. Such a material, for example, would be Nusil Silicon Foam CF3-2350. In a general sense, the pore size or diameter of entrained gas particle should be less than 20% the size of the conducting particle. This material will be a perfectly elastic medium which is compressible.

d) When creating the elastomer sheet, the conventional practice is to use a flat

carrier web. The elastomer takes on the shape of the web. A modified web can be used which has bumps (like the surface of a golf ball) on the same grid as the contact surface. The resulting sheet will have the space needed for the elastomer to flow. It may also be possible to form a carrier sheet which has a bump grid which is much finer than the intended contact grid. This will eliminate the need to orient the elastomer relative to the contact array of the device.

e) Increasing the magnetic field level during ACE manufacture tends to pull the magnetic particles from the surface and create columns with an extra particle thickness in the column, but will leave the rest of the elastomer sheet at its basic thickness. This creates a convoluted surface (with erupted portions aligned with the columns), which provides additional space for the elastomer to move to during compression.

Connectorization using Elastomers

Elastomers can be used in 3 different areas in the connector to optimize the interconnection.

1) ACE as described previously can be used between the device and board to provide electrical contact.

2) A thermally conductive elastomer as described in patents 4,838,347 , Dentini et al Thermal Conductor Assembly, and 4,960,612 Dentini et al Thermal Conductor Assembly Method, can be used to provide high quality thermal contact between the packaged device and the heat sink. In forming these elastomers, they are highly convoluted to maximize thermal contact. These convolutions provide the space needed for the material to flow during compression. The use of a thermal elastomer between the device and heat sink also spreads the compressive load uniformly across the device, reducing the opportunity for

damage to the device.

3) A metal stiffener is normally required on the back side of the printed circuit board to maintain a uniform compressive load between the board and device. An unfilled, insulating elastomer can be placed between the stiffener and board, to assure a uniform load across the surface. Although this material behaves like an incompressible fluid, it will not provide a perfectly uniform load leveling action. This can be corrected by perforating the elastomer with an array of holes. This will allow for local deformation, while assuring a uniform load distribution. Without perforation of the elastomer, or creating space by one of the means described above, true load leveling can not occur.

Device Packaging

All of the discussions above have been focused on the interconnection of device package to board. All of the art can be applied to interconnect device package to device package; board to board; board to flex or any combination of same.

These elastomeric materials can also be used in the packaging of the device itself. Rather than use wire bonding to attach the device to the lead frame package, a very fine pitch elastomer can be used to attach the device to the lead frame or other device interconnect structure. Figure 5a shows a sketch of this concept. In this sketch the chip is sandwiched between 2 layers of elastomer. A top layer provides thermal contact to remove heat from the chip, and a bottom layer provides electrical contact between the chip's pad layer and the ~~lead frame~~.

The combination of elastomers as shown provides excellent mechanical and environmental protection to the chip. Compression of the elastomer would occur as the can is sealed.

Integrated Concepts

The present manufacturing process is based on creating a sheet of ACE for subsequent assembly into an interconnection device. There may be unique opportunities to integrate the manufacturing of the ACE directly into the board or flex circuit manufacturing process. An example of this would be to replace the Mylar carrier sheet by a flex circuit. A sheet of ACE would be formed on the surface of the flex circuit and bonded to it. Interconnection of the flex to the board or device would be facilitated by compressing the flex circuit/ACE to the mating contact using appropriate housing and alignment hardware.

Planirization of BGA devices

The balls of solder have a tolerance on their thickness. The device to which they are attached may have a certain amount of warpage due to the construction process and materials used. As a result, the surface formed by the bottom of the array of solder balls is not a flat plane, but an irregular shape. This puts a stress on the interconnection medium in that it requires the interconnection medium to have a dynamic range which is very large. This limits the choices of interconnection medium, and increases the system cost. When a separable connection is to made with a BGA device, a low cost modification to the package can be made which will planirize the array, allowing it to be readily connectorized.

Using a heated flat surface which is not wetable by solder, the BGA package is pressed against the plate. The temperature of the surface is such that the solder will soften and extrude as the solder ball is pressed against the surface, with the array of solder balls conforming to the heated plate. A controlled compression can be used such that the final

dimension from the top of the package to the plane of the BGA surface is highly controlled. The resulting array of solder balls would now form a true plane. Furthermore, the bottoms of the balls would each have a flat surface. This surface would now be optimized for interconnection using thin ACE materials.

In a preferred embodiment, the heated flat surface could be a Teflon coated hot plate with a regulated temperature control. The final thickness of the device would be controlled by a fixture attached to the hot plate, with a limiting stop which sets the amount of compression of the solder ball.

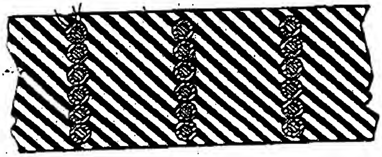

FIG. 1a
(Prior Art)

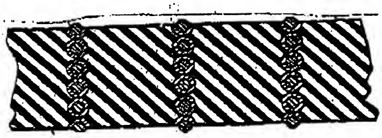

FIG. 1b
(plasma etched)

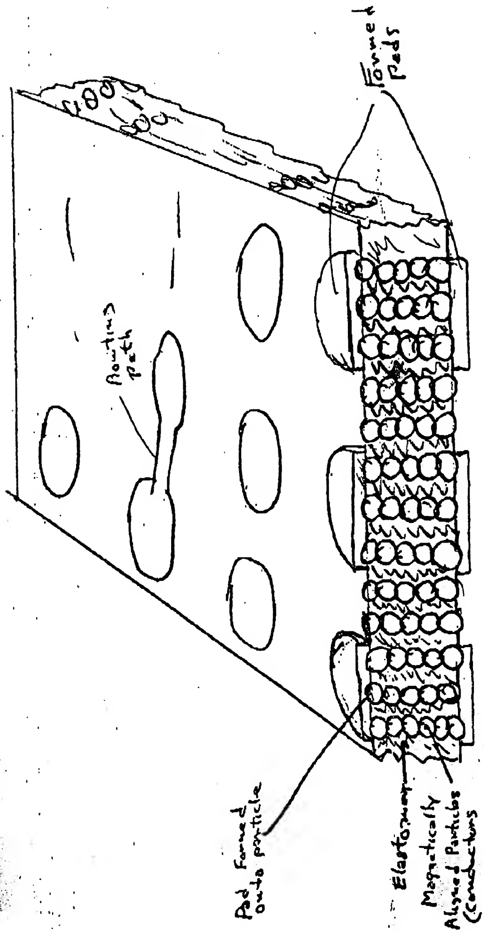

FIG. 1C
(Elastomeric Conductor with Pads)

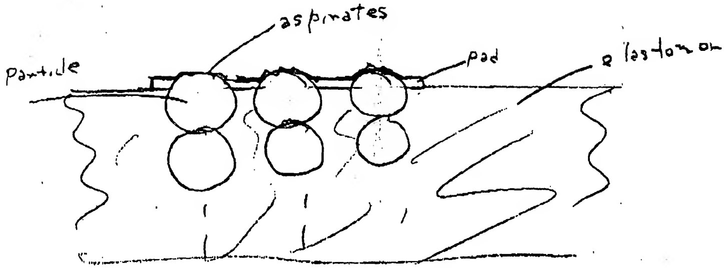

Fig 1f

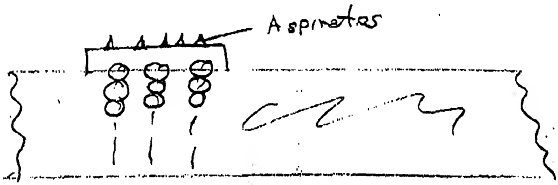

FIG 1g

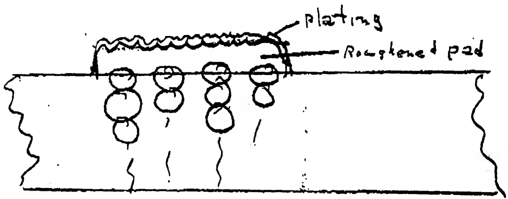

FIG 1h

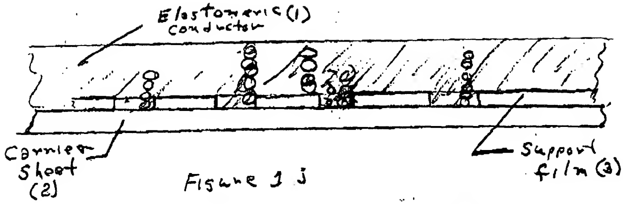

Figure 1 j

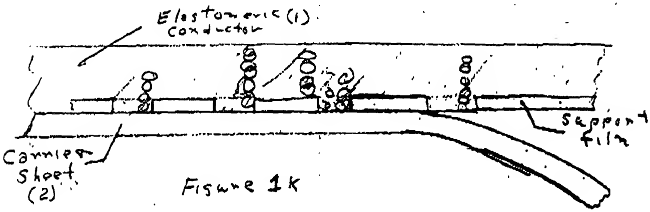

Figure 1k

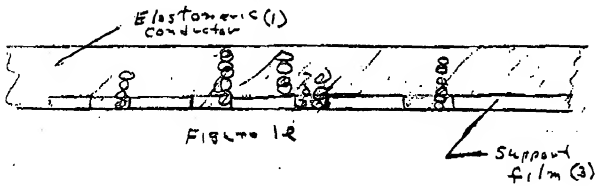

Figure 1l

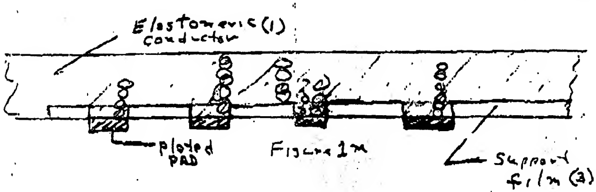

Figure 1m

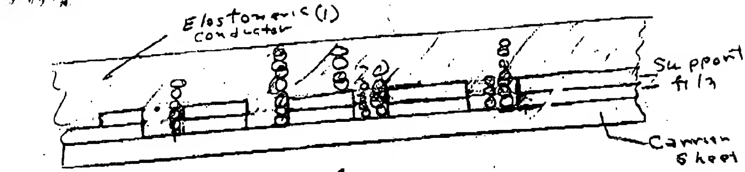

Figure 1n

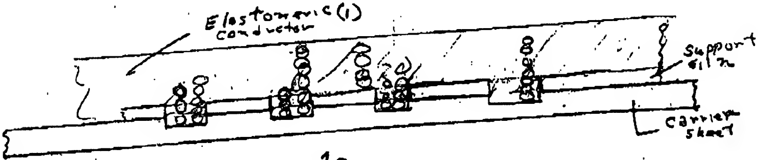

Figure 1p

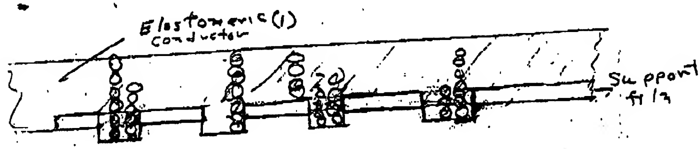

Figure 1q

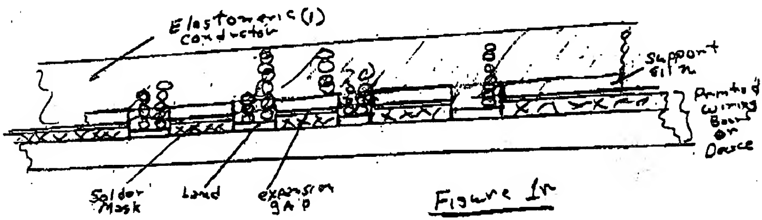

Figure 1r

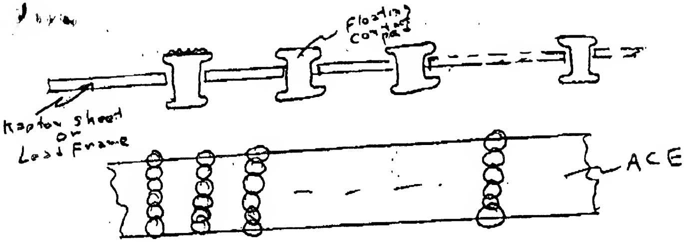

Figure 2a

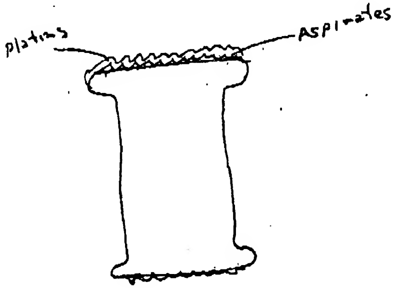

Figure 2b

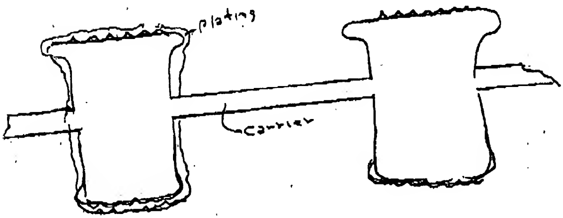

Figure 2c

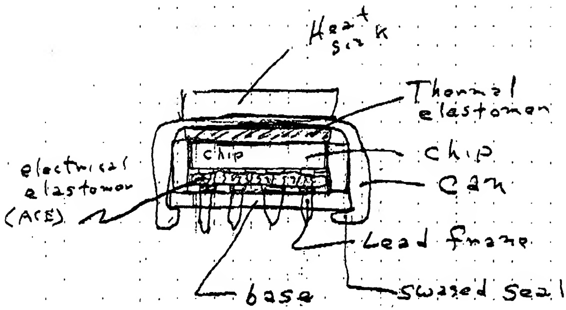
Heat sink
Thermal elastomer
chip
chip
electrical elastomer (ACE)
can
Lead frame
base
swaged seal

Figure 5a